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KUNITOMO SAKURAI

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THE INITIAL STAGE OF DEVELOPMENT OF TYPE IV RADIO BURSTS AND THE RELATION TO EXPANDING MAGNETIC BOTTLES

by

Kunitomo Sakurai*
Radio Astronomy Branch
Laboratory for Extraterrestrial Physics
NASA/Goddard Space Flight Center
Greenbelt, Md. 20771, U.S.A.

ABSTRACT

Using observed data for wide-band type IV solar radio bursts, the onset time differences between the microwave and metric frequencies and the peak flux intensities of the metric component are analyzed as a function of the longitudinal position of associated flares on the solar disk. It is shown that this time difference is dependent of the position of associated flare and that the peak flux intensity reaches maximum when a flare occurs in the region 10 to 40 degrees west of the central meridian of the solar disk. These results are explained by taking into account the eastward expansion of magnetic bottles which trap mildly relativistic electrons responsible for type IV bursts. Discussion is given on the relation between these magnetic bottles and shock waves which excite type II radio bursts.

*NASA Associate with University of Maryland, Astronomy Program

1. INTRODUCTION

Wide-band type IV radio bursts are usually associated with solar proton flares (e.g., Obayashi, 1964; Kundu, 1965; Sakurai, 1973a). Recently, many beautiful records by the Culgoora radio heliograph have shown that the sources for both type II and IV radio bursts at 80 MHz expand from the flare regions with the speed of several 100 km sec^{-1} (e.g., Wild, 1970a; Wild and Smerd, 1972). Furthermore, these records have made clear that the source of type II burst is identified as a shock wave expanding from the flare region and that sources for moving type IV bursts are classified into three distinct types: expanding arch, advancing front and isolated source moving out between open field lines (Smerd and Dulk, 1971). It seems that most sources of these bursts are accompanied by magnetic flux tubes expanding from flare regions, which may be identified as "magnetic bottles". According to Dulk et al. (1971), moreover, the shock waves mentioned above tend to propagate mainly along the magnetic lines of force ambient near and above the flare regions. These observations, therefore, show that the emission mechanism of type II burst is not the same as that of moving type IV burst.

As is well known, moving type IV bursts in metric and decametric frequencies are emitted by gyro-synchrotron mechanism from mildly relativistic electrons, which are accelerated in flares, by their interaction with sunspot magnetic lines of force being stretched outwards. Using the formulae derived by Wild (1970b), Dulk (1970) has recently calculated the distributions of the intensity and polarization for gyro-synchrotron emission from mildly relativistic electrons with respect to the angle between observing direction and the direction of an ambient magnetic field. He has taken into account these distributions to explain changing pattern of the emission characteristics of moving type IV bursts (Dulk, 1970; Smerd and Dulk, 1971).

In this paper, using the results of statistical analysis for some characteristics of type IV bursts, we shall deduce an expanding pattern of magnetic bottles which are the sources of moving type IV bursts. Then, discussion will be given on the relation between type II and moving type IV radio sources.

2. TIME SEQUENCE OF DEVELOPMENT OF TYPE IV RADIO BURSTS

In general, emission of type IV radio bursts starts in microwave frequency and then extends into decimetric and metric frequencies as shown in Fig. 1 (e.g., Wild, 1962). This figure shows that, prior to the emission of the microwave component of the burst, defined as IVμ, microwave impulsive burst (M-W) is first emitted, and that type II radio burst precedes the metric component of moving type IV radio burst (IVmA) in metric and decametric frequencies. These two radio bursts, microwave and type II, make it difficult to estimate exactly the onset times for both microwave and metric components of type IV bursts, but, referring to the original records on time profiles of the flux intensity of these bursts, we are able to deduce these onset times. In this paper, using the results published by Jonah et al. (1965) and in the Quarterly Bulletin of Solar Activity, we have analyzed the onset time difference between the microwave and the metric components for the period 1956 to 1967 as a function of the positions of associated flares in the solar longitude. In doing so, we have considered only type IV bursts associated with solar flares which produced Mev cosmic ray events of prompt-onset type (sometimes, defined as F-type, see, e.g., Obayashi, 1964; Sakurai, 1965a). We have referred to the proton flare data compiled by Obayashi et al. (1967) and Hakura (1968). In this analysis, we have used the frequencies of 8800, 9375; 9400 and 9500 MHz and of 169, 200 and 260 MHz as typical frequencies of microwave and metric type IV bursts, respectively.

The onset time difference mentioned above is shown in Fig. 2. This shows that this time difference becomes larger as the positions of associated flares move eastwards from the west limb of the solar disk. Similar results have been obtained by Sakurai (1964, 1965b) for the period IGY-IGC (1957-1959). More than hundred proton flares were observed during the period for the present analysis. Using the result shown in Fig. 2, we have calculated the mean time delays from microwave to metric type IV emissions for each 30 degrees interval of the solar longitude. These time delays indicate how much the onset of metric type IV bursts is delayed from that of microwave type IV bursts as a function of observing direction to the flare position from the earth. Fig. 3 shows these time delays as a function of this direction with respect to the position of flares.

For instance, this figure indicates that, if we observe an associated flare which occurs 45 degrees east of the central meridian, the time delay mentioned above is about 6.7 minutes on average.

These time delays shown in Fig. 3 suggests that the peak flux intensity of the metric component of moving type IV bursts depends on the position of an associated flare on the solar disk. Fig. 4 shows that the distribution of this intensity depends on the longitude position of associated flares. Moreover, the result shown in this figure indicates that main part of this component is emitted into a wide cone 10 to 40 degrees east of the meridian plane which crosses the position of an associated flare. This fact can be explained by taking into account a magnetic bottle ejected from the flare which expands eastwards a few ten degrees from the flare region with respect to the meridian plane mentioned above: this type of expansion of a magnetic bottle has been suggested previously (see, Takakura, 1961; Sakurai, 1964, 1965a; Dulk, 1970; Smerd and Dulk, 1971). When we refer to the result numerically calculated by Dulk (1970) in explaining the emission characteristics of these bursts as shown in Fig. 4, it is necessary to assume the eastward oriented expansion of a magnetic bottle which trap mildly relativistic electrons responsible for metric type IV bursts. The result shown in Fig. 4 cannot be explained by using a model of spherically expanding shock wave emitted from an associated flare, although this was once suggested by Sakurai (1964, 1970): the electrons responsible for type IV bursts are not stably captured by the shock wave itself during its propagation. It also seems difficult to explain the result shown in Fig. 2 by taking into account shock waves expanding through the solar atmosphere near and above the flare regions because an expanding pattern of these shock waves deduced from radio heliograph observation is quite different from that of magnetic bottles which have been estimated here (e.g., Dulk et al., 1971; Sakurai and Chao, 1973; Sakurai, 1973b).

3. RELATION BETWEEN EXPANDING MAGNETIC BOTTLES AND TYPE II RADIO SOURCES.

The results shown in Figs. 2-4 seem to be useful for estimating an expanding pattern of the magnetic bottles which trap the electrons accelerated in flares. As noted by Schatten (1970), the speed of expansion of these magnetic bottles is 200 - 300 km sec^{-1}. This value seems to be consistant with those which have been obtained by Smerd and Dulk (1971). In the case of the 4 November 1968 proton event, the speed of type II radio source is estimated as ~2600 km sec^{-1} by Sakurai et al. (1973) using the plasma distribution in the outer solar atmosphere (Stelzried et al., 1970). Moreover, the mean speed of the interplanetary shock wave associated with a flare, which occurred at 0513 UT, is estimated as ~650 km sec^{-1} (Sakurai et al., 1973). These two speeds estimated here are much higher than that estimated by Schatten for an associated magnetic bottle. As suggested by Smerd et al. (1971), we can, therefore, conclude that the source for type II bursts is not the same as that of moving type IV bursts in metric frequency.

An expanding pattern of shock waves, which are identified as the sources of type II bursts, is quite different from that of magnetic bottles: that is, shock waves mostly propagate along magnetic field lines ambient near and above sunspot groups, in which associated flares occur (Dulk et al., 1971; Smerd et al., 1971). Taking into account a current view for typical configuration of sunspot magnetic field (e.g., Altschuler and Newkirk, 1969; Newkirk, 1971; Rust, 1972), we propose a model for the expanding magnetic bottle ejected from the flare region (Fig. 5). In this case, we have taken into account the emission characteristics such as shown in Figs. 2 and 3 by rëferring to theoretical results by Dulk (1970). As shown by chain lines in this figure, expansion of the magnetic bottle is inclined eastwards a few ten degrees with respect to the meridian plane which crosses the flare position. At the frontal portion of this magnetic bottle, the intensity of the magnetic fields would be weakest as a result of non-uniform expansion since this intensity seems to decrease inversely proportional to the square of distance from the flare region (Smerd et al., 1971). This property is useful for explaining the observed time delay shown in Fig. 2. Since the highest intensity is usually observed in the direction perpendicular to the field lines which constitute the magnetic bottles (Dulk, 1970), this characteristic seems to be useful to explain the result shown in Fig. 3. This problem, however, must be investigated in future.

4. DISCUSSION

Cosmic ray particles, consisting of protons, helium and other heavier nuclei, are accelerated simultaneously with mildly relativisitic electrons in solar flares. Some nuclear particles are injected into interplanetary space from the region where they are accelerated.

The U-shaped peak flux frequency spectrum of type IV radio bursts is usually associated with proton flares (e.g., Sakurai, 1963, 1969; Castelli et al., 1967, 1968). Furthermore, the association of moving type IV bursts in metric frequency is very important for the injection of those nuclear particles into outer space. In fact, solar flares which are not followed by this metric component, in general, do not accompany the emission of these particles even if an intense emission is observed in microwave frequency (Sakurai, 1963, 1973a). In these events, radio burst of the U-shaped spectrum is not associated. This suggests that the emission of moving type IV burst in metric frequency is closely related to the injection mechanism of energetic nuclear particles. As mentioned in the last section, the emission of this moving burst is accompanied by the expansion of a magnetic bottle which trap mildly relativistic electrons. It seems, therefore, that the expanding motion of the magnetic bottle disturbs the configuration of sunspot magnetic fields near and above the flare region, and then make it possible for accelerated nuclear particles to be efficiently released into interplanetary space.

5. CONCLUSION

Using the observed data on characteristics of type IV bursts, we have examined both the onset time difference between microwave and metric emissions of the bursts and the peak flux intensity of the metric emissions as a function of the longitude position of associated flares on the solar disk. The results show that this time difference depends on the position of associated flares (Figs. 2 and 3) and that the maximum peak flux intensity is associated with flares which occur in the region 10 to 40 degrees west of the central meridian of the solar disk (Fig. 4).

These results have been explained by taking into account a non-uniform expansion of magnetic bottles which trap mildly relativisitic electrons responsible for type IV bursts. In explaining the characteristics shown in Figs.

2 - 4, it has been proposed that the bottles expand 10 to 30 degrees eastwards from the meridian plane which crosses the flare regions. These bottles seem to be ejected from the flare regions into outer space, but the direction of their movement does not coincide with that of shock waves which excite type II radio bursts (Fig. 5). This type of expansion of magnetic bottles from the flare regions seems to play an important role for injection of solar cosmic rays into interplanetary space.

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CAPTION OF FIGURES

Fig. 1 - Typical pattern of development of solar radio bursts associated with a flare. The origin of time is referred to as the onset time of the flare (Wild, 1962).

Fig. 2 - Time differences between the microwave and metric emissions of type IV bursts with respect to the longitude positions of associated flares.

Fig. 3 - Polar diagram of the mean time differences between the microwave and metric emission of type IV bursts with reference to the position of an associated flare.

Fig. 4 - Distribution of the peak flux intensity of metric type IV bursts with respect to the solar longitude.

Fig. 5 - Proposed model for expanding patterns of shock waves and magnetic bottles. Chain lines show a deformation of sunspot magnetic field lines which constitute a magnetic bottle.

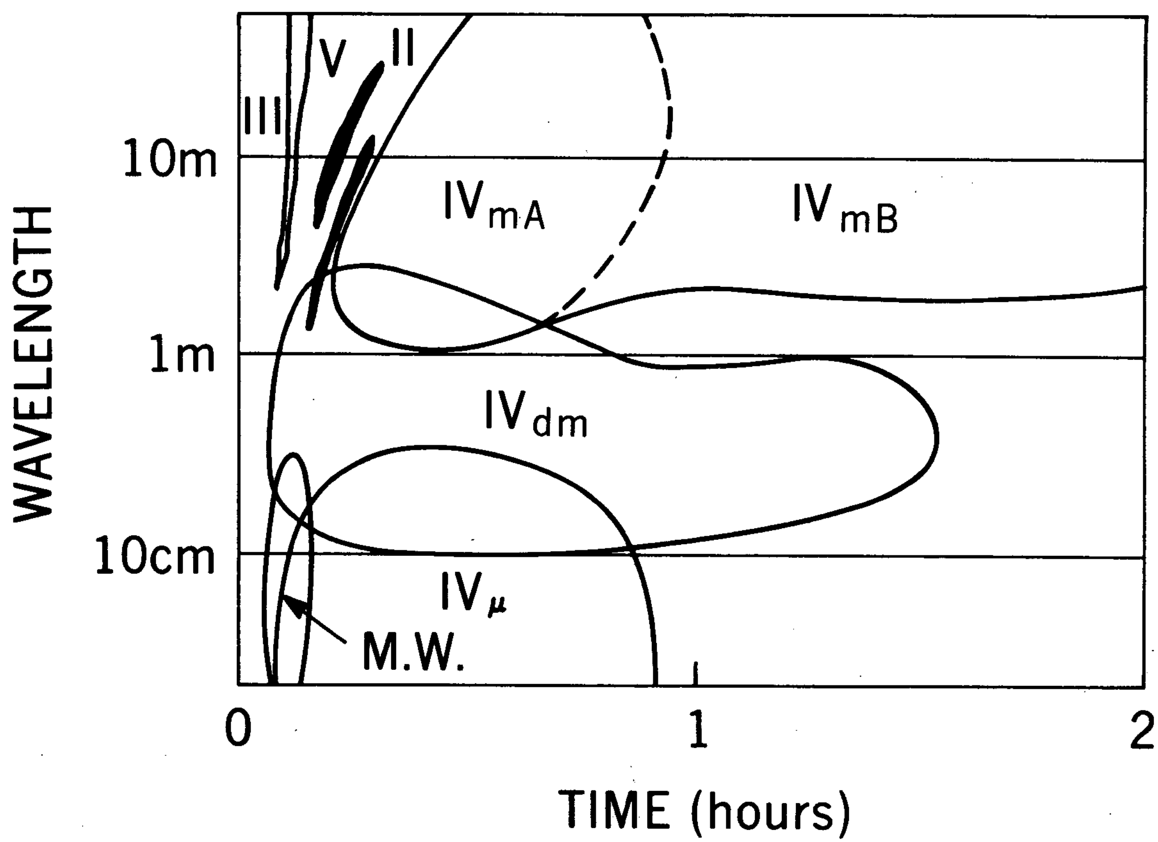
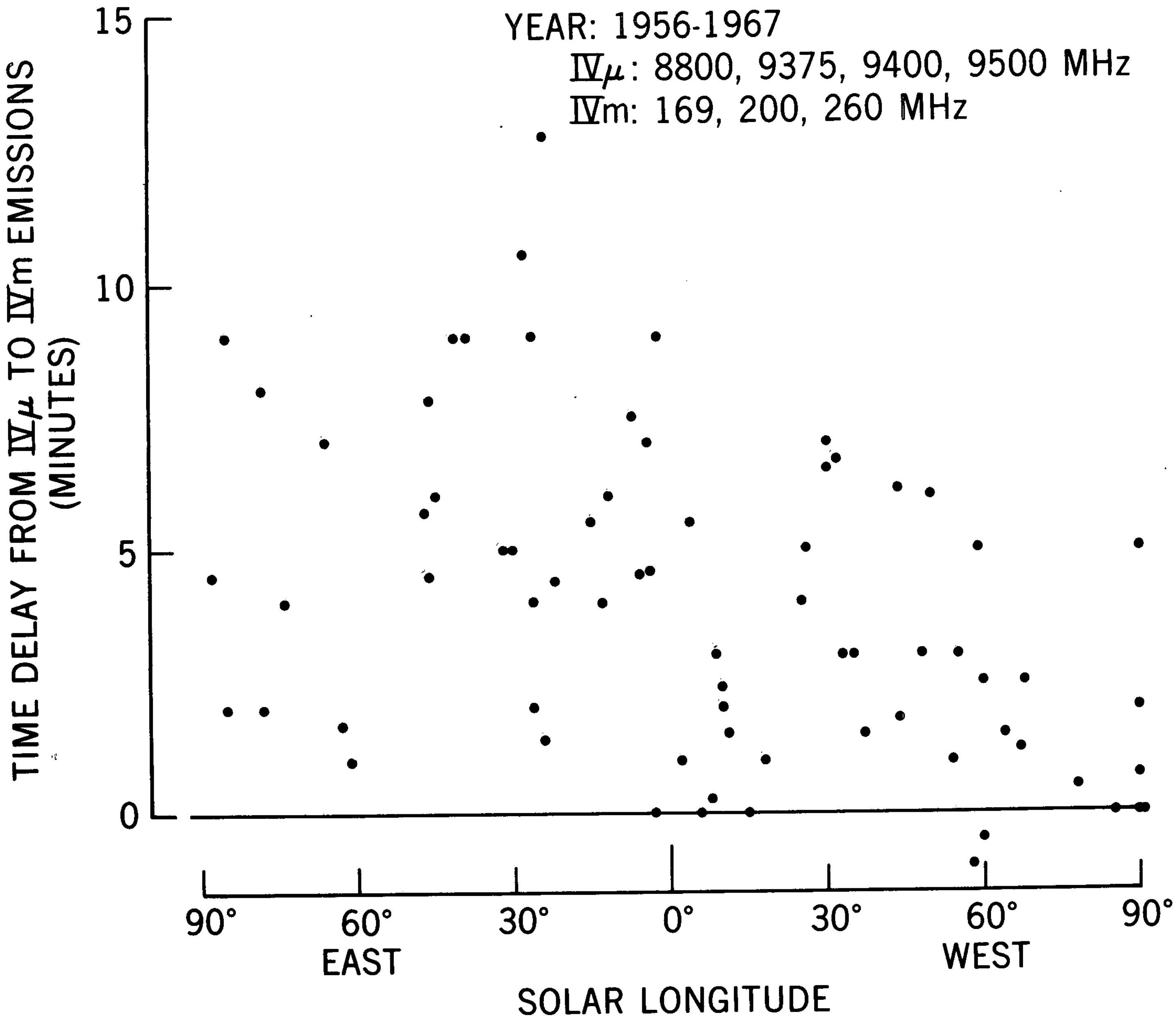

WAVELENGTH
10m
1m
10cm
III
V
II
IV$_{mA}$
IV$_{mB}$
IV$_{dm}$
IV$_{\mu}$
M.W.
0
1
2
TIME (hours)

Fig. 1



YEAR: 1956-1967
IVμ: 8800, 9375, 9400, 9500 MHz
IVm: 169, 200, 260 MHz
TIME DELAY FROM IVμ TO IVm EMISSIONS (MINUTES)
15
10
5
0
90°
60°
30°
0°
30°
60°
90°
EAST
WEST
SOLAR LONGITUDE

Fig. 2

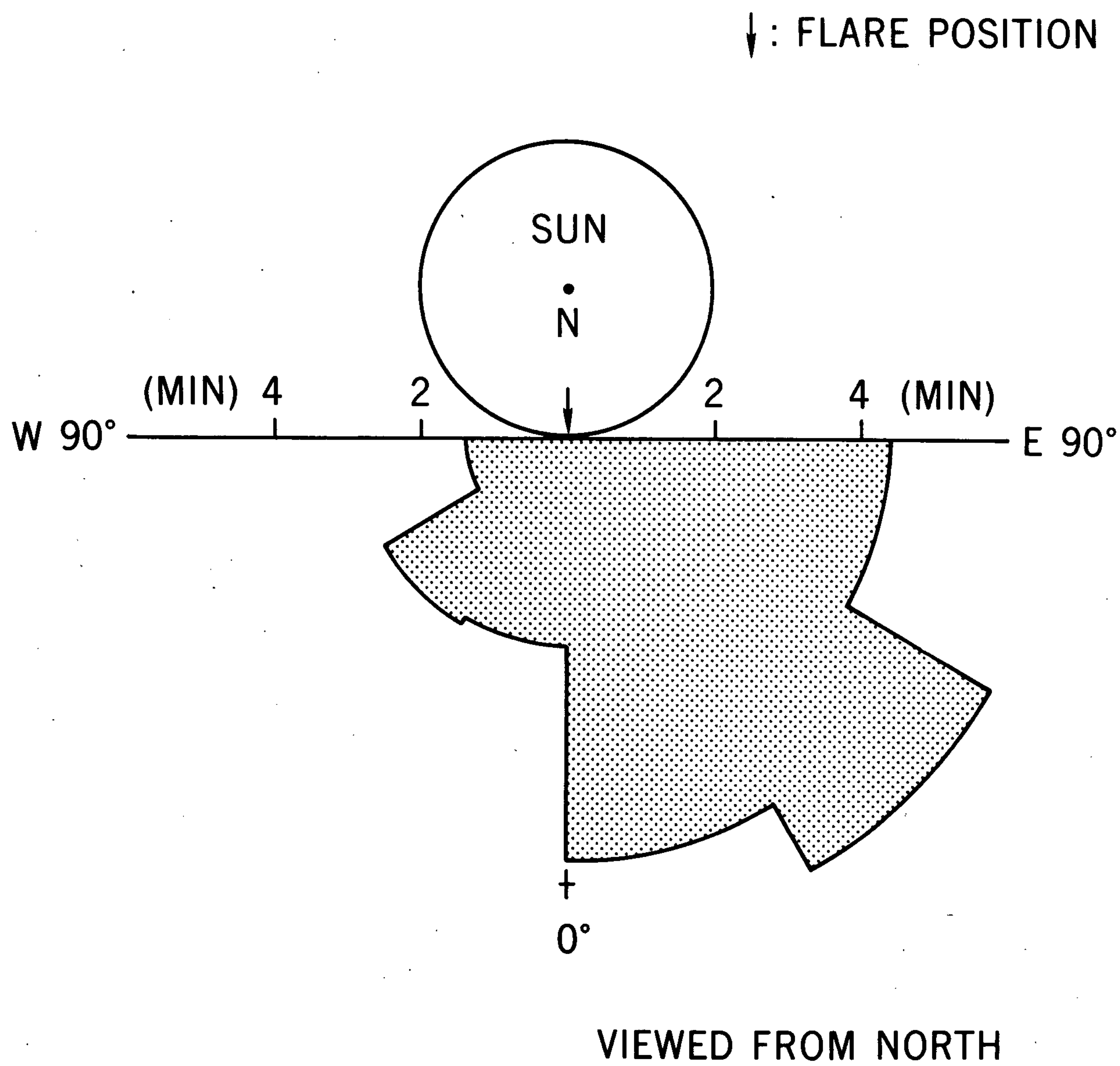


Fig. 3

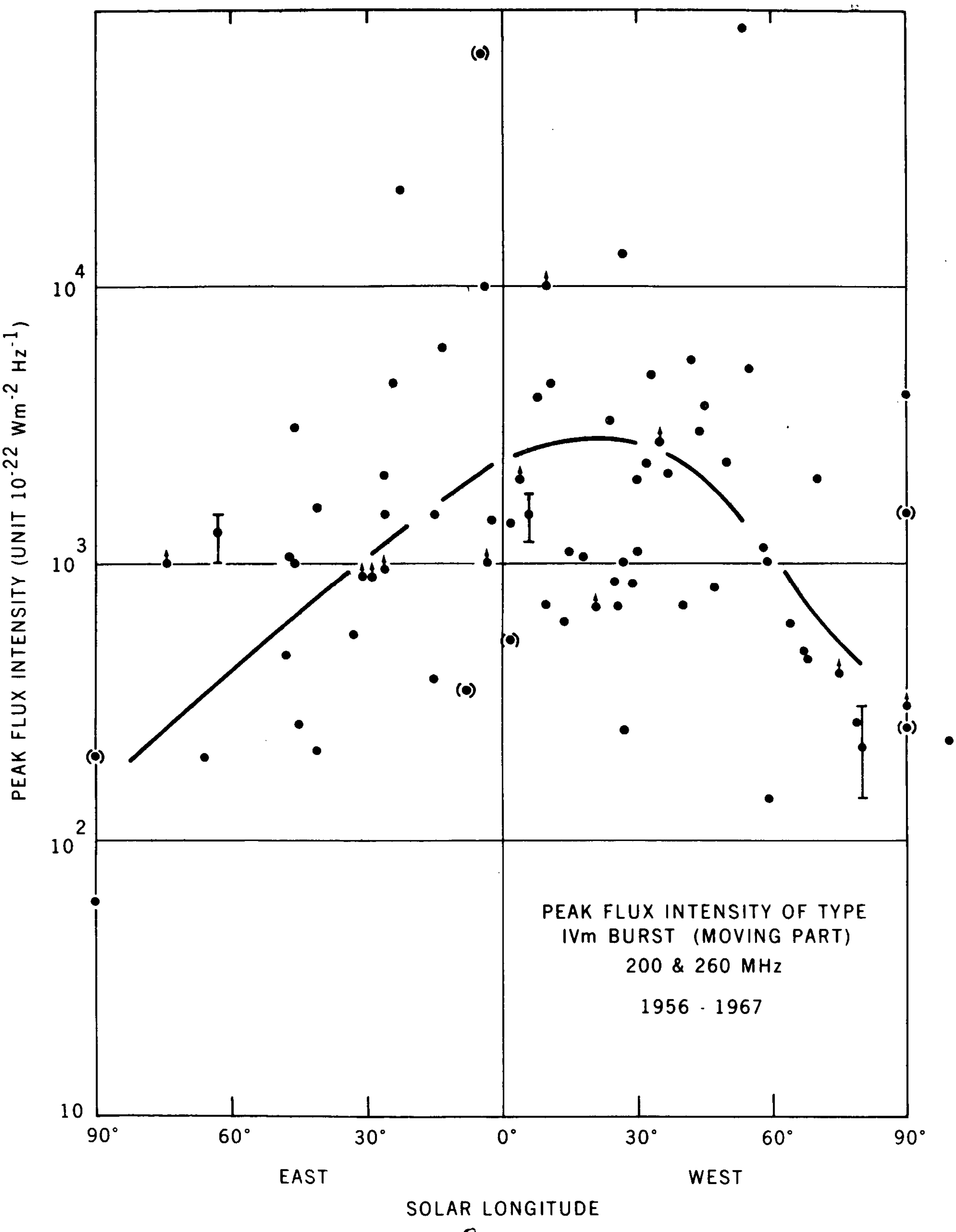

PEAK FLUX INTENSITY (UNIT 10^{-22} Wm^{-2} Hz^{-1})
10^4
10^3
10^2
10
90°
60°
30°
0°
30°
60°
90°
EAST
WEST
SOLAR LONGITUDE
PEAK FLUX INTENSITY OF TYPE
IVm BURST (MOVING PART)
200 & 260 MHz
1956 - 1967

Fig. 4

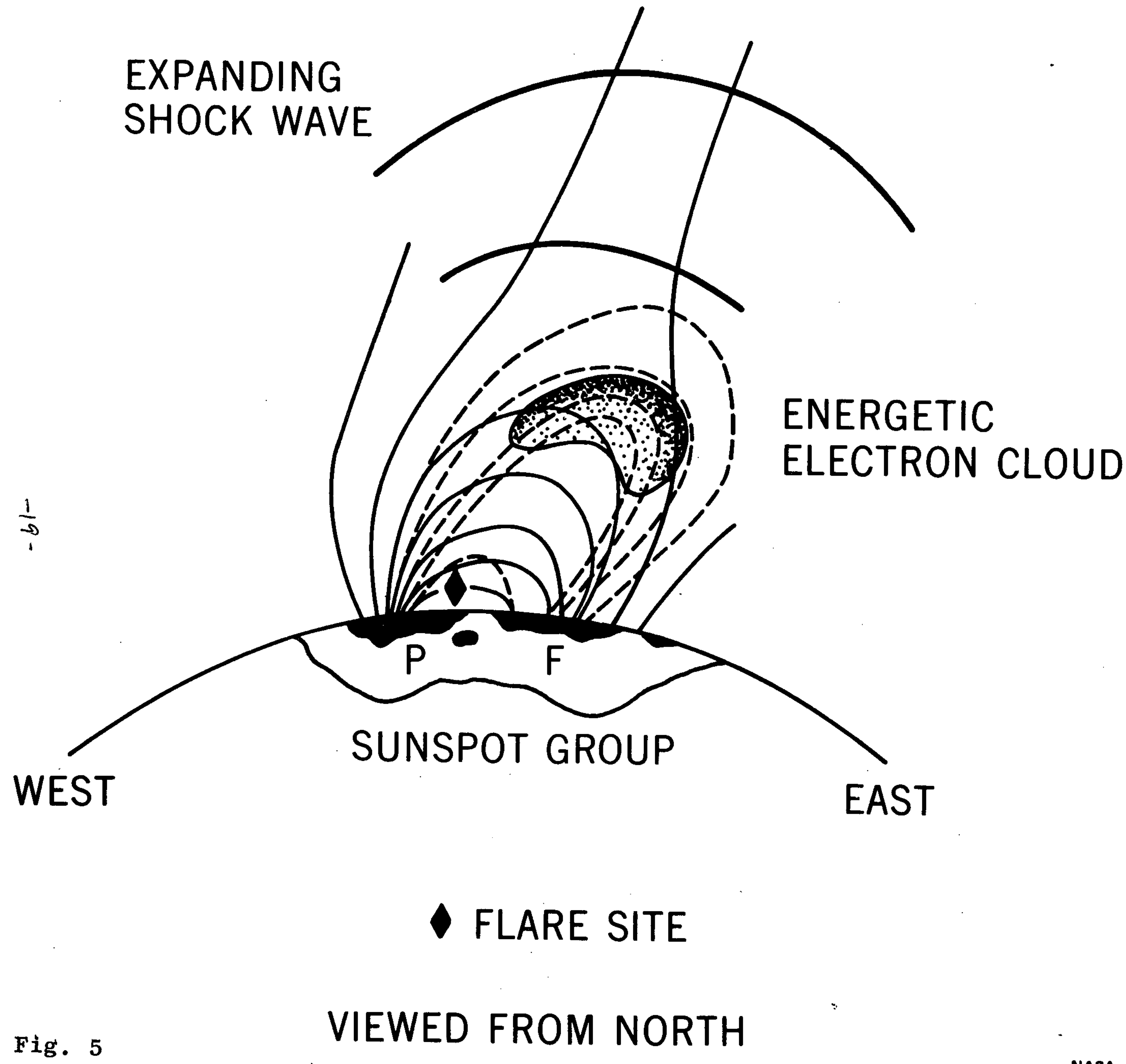


Fig. 5

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